

An Electrochemical Framework to Explain the Intergranular Stress Corrosion Path of Two Al-Cu-Mg-Ag Alloys, C415 and C416

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INTRODUCTION

Precipitation age hardenable aluminum alloys have been studied by the aerospace industry for over 50 years. Al alloys that offer improved combinations of strength, toughness, and weight reduction are always desirable, particularly Al-Cu alloys. These alloys however, often exhibit susceptibility to localized corrosion and stress corrosion cracking (SCC). It has been well documented in literature that SCC initiates from localized corrosion sites¹⁻³ but, the transition from localized corrosion to SCC is not well understood. Al-Cu alloys can exhibit a “window” of SCC susceptibility as a function of aging time, with the resistance to SCC increasing with over-aging.⁴⁻⁷ Electrochemical-based mechanisms for intergranular corrosion (IGC) and intergranular SCC (IGSCC) are based on a preferential anodic path along the grain boundaries.⁷ This active region is thought to be due to solute depleted zones, anodic precipitates, or equilibrium or non-equilibrium segregation.^{4,5,7-10} It has been well documented that the Cu content in solid solution in Al alloys directly correlates to the pitting potential of the Al-Cu aluminum alloys.¹⁰ Increasing the Cu content in solid solution increases the pitting and repassivation potentials associated with the alloy matrix. However, Cu depletion at grain boundaries is then linked to IGSCC susceptibility.

This study focuses on the localized corrosion and SCC resistance of two emerging, advanced Al-Cu-Mg-Ag alloys, C415 (Al-5%Cu-0.8%Mg-0.5%Ag-0.6%Mn) and C416 (Al-5.4%Cu-0.5%Mg-0.5%Ag-0.3%Mn), in the UA, T8, and T8 + thermal exposure of 5000 h at 225°F (T8⁺) conditions. Ag was added to promote the precipitation of the Ω -phase.^{11,12} In C416, θ' (Al₂Cu) and Ω (Al₂Cu) intermetallic phases are present and responsible for strengthening through precipitation age hardening.¹³ In C415, the Ω , S (Al₂CuMg), and, possibly, the θ' intermetallic phases are present.¹⁵ The lower ratio of Cu/Mg and greater Mn content promotes S formation in C415.¹³ The large number of these intermetallics on the grain boundaries leads to the Cu-depletion at the grain boundaries. The main goal of this study is to characterize the localized corrosion and IGSCC properties of these alloys as a function of metallurgical conditions in the context of the classical electrochemical framework.

EXPERIMENTAL PROCEDURE

Alternate Immersion (AI) studies (ASTM G44/49) were performed on C415 and C416 in both tempers with unstressed and stressed samples using a 3-point loaded specimen jig (ASTM G-39). Serial removals and post-test examination using optical microscopy and SEM was performed to characterize the IGSCC susceptibility of these alloys in the T8 and T8⁺ conditions. Constant extension rate testing (CERT) was performed on both alloys in the UA, T8, and T8⁺ conditions in deaerated, alkaline 0.006 M NaCl (pH~10) to characterize the IGSCC susceptibility and the effect of aging on this susceptibility. The electrochemical properties of the alloys were characterized by analyzing bulk analogs as models of the various components and phases of C415 and C416 in deaerated, alkaline 0.6 M NaCl (pH~10) to establish the electrochemical framework. X-ray diffraction was performed to determine the approximate solid solution Cu content of the matrix of various tempers of the alloys.

RESULTS AND DISCUSSION

AI showed that both alloys were susceptible to SCC in the T8 temper. Notably, resistance to SCC improved in

T8⁺, with the largest improvement in the C416 alloy. Pits formed at constituent particles in all tempers but transitioned to IGC. These pits have an intergranular nature and IGC or IGSCC propagated from pits only. This suggests that a specific pit chemistry is necessary to initiate IGC. Since IGSCC occurred in both alloys in the T8 condition, a common feature such as Cu depletion at the grain boundaries is suggested. The difference in susceptibility between the alloys and tempers is of a degree since more severe IGC and IGSCC was observed in the T8 temper for both alloys but, was not completely eliminated in the T8⁺ tempers.

CERT showed a dramatic improvement in time-to-failure and %IG fracture with increased aging from the UA to the T8 conditions. Only a small improvement was seen with further aging to the T8⁺ condition.

The critical potentials of C415 and C416, in both tempers, are lower than that of solution heat-treated (SHT) Al-4%Cu but higher than that of pure Al (99.99%). E_{tp} decreased in both alloys as the aging time increased. The Al-4%Cu (SHT) simulates the matrix prior to the Cu-depletion and the pure Al simulates the maximum Cu-depletion possible at the grain boundaries. Since S-phase actively dissolves in aqueous solutions and θ -phase resists corrosion in aqueous solutions compared to pure Al, then the S-phase could explain the persistence of the more active grain boundary path in C415 compared to C416, in the T8⁺ condition. An electrochemical framework based on Cu-depletion could also explain IGC and IGSCC susceptibility as used by Galvele¹⁰ and Sugimoto⁵. IGSCC susceptibility in the T8⁺ condition would be eliminated if the pitting potential of the matrix was lowered to that of pure Al due to Cu-depletion from the matrix since the preferential grain boundary path would be eliminated. E_{tp} and XRD results indicated that the matrix Cu content decreased in the alloys from the UA→T8→T8⁺→OA conditions, suggesting a leveling of the Cu content with overaging. In summary, the susceptibility of these alloys to IGSCC is due to Cu-depletion and the resistance improves with over-aging due to leveling of the Cu concentration between the matrix and grain boundaries.

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